Control of self-limited (0001) facet in selectively grown GaN hexagonal structures With dot patterned mask

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Selective Area Growth(SAG) technique in GaN is useful method for the fabrication of both semiconductor microstructure devices such as field emission devices[1] and optoelectronic devices. GaN hexagonal pyramids have been recently demonstrated by this technique on hexagonal and dot patterned mask openings. Also these pyramid structures with low threading dislocation density can form a high-finesse cavity and demonstrate laser action. For practical field emitter applications, the tip sharpness, symmetry and height uniformity of GaN pyramids must be optimized through the proper growth conditions. Specially truncated hexagonal pyramid structures having self-limiting (0001) facets[2] should be overcome to obtain sharp tips. Also, it was found that the spatial control of In incorporation in InGaN quantum structures in SAG[3] can be directly determined by the geometry of the mask and GaN hexagonal template films with self-limiting (0001) facets. Therefore, a better understanding of the growth mechanism in SAG is necessary to control the self-limited plane for the realization of GaN hexagonal sharp pyramid and micro-disk arrays. This will make the SAG a highly promising technique for the development of a next generation of non-planar optoelectronic devices. In this study, we will discuss systematically the growth mechanism of GaN hexagonal microstructures on dot patterned GaN/sapphire substrates by selective MOCVD. We also present the control of self-limited (0001) facet of GaN pyramids for the realization of sharp tips or micro-disk depending on the growth conditions such as growth pressure, temperature, and fill factor.

The hexagonal microstructures of GaN were grown on 2 ㎛–thick-GaN/sapphire substrates by using low-pressure MOCVD. The GaN films were deposited with 100 nm-thick SiO_2 using plasma enhanced chemical vapor deposition. Mask openings were defined using lithography and etching with BOE. The window openings fixed with circles of 5.5 μm width and the mask spacing ranges of fill factor from 0.04 to 0.24. The growth temperature ranged from 950 ℃ to 1150 ℃, and the growth pressure from 75 torr to 750 torr.

The {1-101} facet of a GaN hexagonal microstructure is more stable than top (0001) over large range of growth pressure and growth temperature in SAG on dot pattern. We found out the fact that the nucleation of this top (0001) facet depends on Ga-diffusion length. The Ga-diffusion length is mainly depended on the growth pressure and the growth temperature. The (0001) surface of GaN microstructures grown at 950 ℃ and 750 torr was not flat and coarse. It seems that the surface was composed of many and tiny hexagonal microstructures, which had six (1-101) facets, at the initial stage. As the growth pressure decreased, partially flat (0001) facet appeared such like truncated pyramid. It is due to increase of the lateral growth rate at low growth pressure. However, at 950 ℃ and 75 torr, the vertical growth rate through this flat (0001) facets was too slow owing to low growth temperature. Therefore, at this conditions, {1-101} facet growth was more dominant than (0001) facet growth (Fig. 1 (a)). As the growth temperature increased, the vertical growth rate as well as the lateral growth rate also increased because of both increases of Ga-diffusion length and Ga-adatom concentration (Fig. 1 (b)). Under proper conditions, we can make hexagonal micro-disk arrays with completely flat (0001) surface (Fig 2). As a consequence, this flat (0001) facet can be controlled by the growth pressure, temperature, time and even fill factor. In case of low fill factor, more Ga-flux from more large SiO_2 area arrived at the top (0001) surface and the growth rates increases and then the total size of hexagonal structures increased (Fig 1 (c)). For fabrication sharp tips, we have to avoid the formation of the self-limited (0001) facets on the top surfaces of pyramid structures. GaN hexagonal pyramid arrays with 50 nm-radius tip were successfully achieved with relatively low growth temperature and high growth pressure (Fig 3). We will discuss more about the details of the growth modes of GaN hexagonal structures in SAG at this coming conference.

Reference

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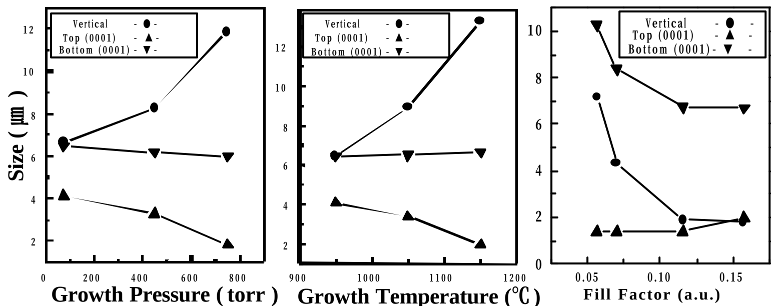
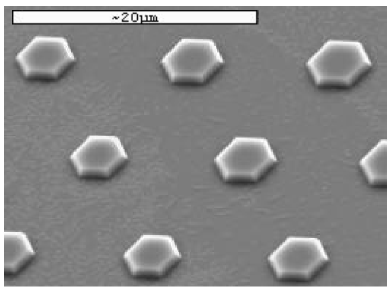


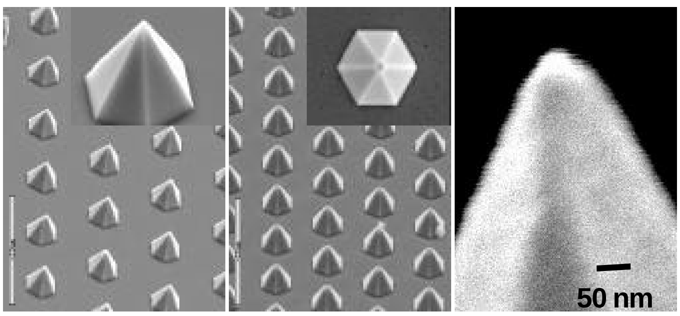
(a) At 950 ℃, F= 0.16 (b) At 75 torr, F = 0.16 (c) At 1150 ℃, 75 torr

Fig. 1 Sizes of height, top (0001) surface and bottom (0001) of GaN microstructures as a function of the growth pressure, the growth temperature and the fill factor.



At 1150℃, 75 torr

Fig. 2 SEM image of the GaN hexagonal micro-disk arrays with completely flat (0001) surface



(a) (b) (c)

Fig. 3 SEM images of the GaN hexagonal pyramid arrays having sharp tips and the microstructures having the self-limited (0001) facets